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Application No.	S980488
Date of Filing	18 June, 1998
Applicant	UNIVERSITY COLLEGE CORK, a university established by Statute of the Republic of Ireland of College Road, Cork, Ireland.

Dated this 28 day of June 1999.

An officer authorised by the
Controller of Patents, Designs and Trademarks.

FORM NO. 1

S980

REQUEST FOR THE GRANT OF A PATENT

PATENTS ACT, 1992

The Applicant(s) named herein hereby request(s)

[ ] the grant of a patent under Part II of the Act

[X] the grant of a short-term patent under Part III of the Act

on the basis of the information furnished hereunder.

1. Applicant(s)

Name	UNIVERSITY COLLEGE CORK
Address	College Road, Cork, Ireland.
Description/Nationality	A university established by Statute of the Republic of Ireland

2. Title of Invention — "A semi-conductor device"

3. Declaration of Priority on basis of previously filed application(s) for same invention (Sections 25 & 26)

Previous filing date	Country in or for which filed	Filing No.

4. Identification of Inventor(s)

Name(s) of person(s) believed by Applicant(s) to be the inventor(s)

JOHN GERARD MCINERNEY and PETER MATTHS WIPPEL SKOVGAARD

Address

The Creamery, Caum, Macroom, County Cork, Ireland, an Irish citizen, and 308 Bruach Na Laoi, Union Quay, County Cork, Ireland, a Danish citizen, respectively.

CONTINUED OVER

5. [illegible]

The Applicant has derived the right to be granted a Patent from the inventors by virtue of a Deed of Assignment

6. [illegible]

X	Prescribed filing fee £[illegible]
	Specification containing a description and claims
X	Specification containing a description only
X	Drawings referred to in description or claims
	An abstract
	Copy of previous application(s) whose priority is claimed
	Translation of previous application whose priority is claimed
	Authorisation of Agent (this may be given at 8 below if this Request is signed by the Applicant(s))

7. Divisional Application(s)

The following information is applicable to the present application which is made under Section 24 -

Earlier Application No:
Filing Date:

8. Agent

The following is authorised to act as agent in all proceedings connected with the [illegible] and in relation to any patent granted -

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F.R. [illegible]RMAN & CO.	[illegible] Merrion Square, Dublin 2, Ireland.

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F.R. [illegible]RMAN & CO., at its address as recorded for the time being in the Register of Patent Agents.

For: University College, Cork

Secretary & Bursar

18 JUN 1998

"A semi-conductor device"

The present invention relates to a semi-conductor device, and in particular, though not limited to an optical semi-conductor device, for example, a semi-conductor laser device.

Semi-conductor lasers, in particular, diffraction-limited high-brightness laser devices are suitable for a wide range of applications, for example, free space communication, and pumping of fibre lasers and amplifiers. Wide stripe semi-conductor lasers with relatively broad current stripes, for example, current stripes of the order of 100 micrometres or more tend to be transversely unstable, and suffer from filamentation and transverse mode beating. Insertion of mode filters, for example, cavity spoilers or saturable absorbers into such devices tends to enhance the modal performance by discriminating against higher order modes.

In relatively large area devices, both lasers and amplifiers, the carrier density tends to increase along the edges of the gain region. This in general, is a feature of both flared and non-flared (broad area) devices. It is believed that the reason for the increase in carrier density along the edges of the active region is due to the shape of the transverse mode profile which results in relatively small field intensities at the edges of the active region. The relatively small field intensity at the edges of the active regions is unable to saturate the gain, which in turn grows to relatively large values. These relatively large values of carrier density along the edges of the gain regions decreases the stability of the device, and thereby, the quality of the far-field.

It is therefore desirable in many cases in semi-conductor electronic and optical devices to control the distribution of electric current conducted through such devices. It is known that current distribution can be controlled by using multiple contacts

with different voltages applied to various of the contacts, however, this requires the generation of many voltage levels for applying to the contact, and also the provision of many connections to the various contacts. This is unsatisfactory in integrated circuit technology. It is also known that current distribution may be varied by localised ion implantation into the semi-conductor material for altering the conductive properties of the material. However, this can lead to other problems and disadvantages with the semi-conductor device.

There is therefore a need for an optical semi-conductor device which allows the current distribution to be controlled without the disadvantages and problems of prior art techniques. Indeed, there is a need for a semi-conductor device in which the current density profile of an active region of a junction in the semi-conductor material of the device can be controlled.

The present invention is directed towards providing such an optical and/or semi-conductor device.

According to the invention there is provided a semi-conductor device comprising a semi-conductor medium which defines a junction, and a first electrical contact and a second electrical contact, the respective electrical contact being located spaced-apart from each other on the semi-conductor medium and in electrical contact with the semi-conductor medium for pumping current through the junction, at least one of the first and second electrical contacts defining an outline contact area with the semi-conductor medium for defining an active region of the junction, and at least one of the first and second electrical contacts defining an effective electrical contact area in which that electrical contact is in effective electrical contact with the semi-conductor medium, the effective electrical contact area being varied within the outline contact area for varying the current density in the active region.

In one embodiment of the invention the first electrical contact defines the outline contact area, and also defines the effective electrical contact area.

In another embodiment of the invention the effective electrical contact area is varied as a function of the desired variation in current density.

In a further embodiment of the invention the effective electrical contact area is varied in direct proportion to the desired variation in current density.

In a still further embodiment of the invention the effective electrical contact area is varied in a direction in which the current density is to be varied.

In one embodiment of the invention the effective electrical contact area is reduced for reducing the current density, and advantageously is progressively reduced for progressively reducing the current density.

In another embodiment of the invention the effective electrical contact area is varied transversely across the active region. In an alternative embodiment of the invention the effective electrical contact area is varied in a longitudinal direction along the active region. In a further alternative embodiment of the invention the effective electrical contact area is varied in both the transverse and longitudinal direction.

In a still further embodiment of the invention the effective electrical contact area is maintained constant in a direction at right angles to the direction in which the effective electrical contact area is varied.

In a further embodiment of the invention the junction defined by the semi-conductor medium is a p-n junction.

In one embodiment of the invention the first and second electrical contacts are located on respective opposite sides of the semi-conductor device.

In one embodiment of the invention the semi-conductor device is an optical semi-conductor device, the longitudinal direction of the active region being defined by the direction of light propagation.

Preferably, the effective electrical contact area is varied for forming a current density profile in the active region which substantially coincides with the light intensity profile in the active region.

In one embodiment of the invention the effective electrical contact area is varied transversely across the direction of light propagation for inducing a current density in the active region, the transverse profile of which substantially coincides with the transverse light intensity profile in the corresponding location of the active region.

In one embodiment of the invention the first electrical contact is formed to define a plurality of effective electrical contact areas which are in electrical contact with each other, the effective electrical contact areas defining areas of non-contact therebetween, the distance between adjacent effective electrical contact areas being sufficiently small that the current density in areas of the active region which correspond to the non-contact areas between the adjacent effective electrical contact areas is greater than zero.

In another embodiment of the invention the first electrical contact comprises a main contact which defines a primary effective electrical contact area, and a plurality of spaced-apart secondary contacts which define respective secondary effective electrical contact areas, the secondary contacts being electrically connected to the main contact.

Preferably, the secondary contacts are provided by a plurality of elongated spaced-apart substantially parallel fingers extending from the main contact, and preferably, the fingers forming the secondary contacts taper from their respective proximal ends to their distal ends. Preferably in the case of an optical semi-conductor device the spacing between adjacent edges of the adjacent secondary contacts in the direction transversely of the direction in which the current density is to be varied is less than the effective diffusion distance in the active region for avoiding induced grading in the profile of the current density in the direction transversely of the direction in which the current density is to be varied.

In an alternative embodiment of the invention the effective electrical contact area is reduced by forming holes or openings in the first electrical contact, the variation in the effective electrical contact area being achieved by varying the number of holes or openings or their respective areas.

In a further alternative embodiment of the invention the effective electrical contact area is reduced by forming a plurality of secondary contacts in the area in which the effective electrical contact area is to be varied, the variation in the effective electrical contact area being achieved by varying the spacing between the secondary contacts, and/or their respective areas.

The invention also provides a method for varying the current density in an active region of a junction defined by a semi-conductor medium of a semi-conductor device, the method comprising placing a first electrical contact and a second electrical contact at spaced-apart locations from each other on the semi-conductor medium, and in electrical contact with the semi-conductor medium for pumping current through the junction, and at least one of the first and second electrical contacts defining an outline contact area with the semi-conductor medium for defining an active region of the junction, and at least one of the first and second

electrical contacts defining an effective electrical contact area in which that one of the first and second electrical contacts is in effective electrical contact with the semi-conductor medium, the effective electrical contact area being varied within the outline contact area for varying the current density in the active region.

In one embodiment of the invention the first electrical contact defines the outline contact area, and also defines the effective electrical contact area.

In another embodiment of the invention the effective electrical contact area is varied in proportion to the desired variation in current density.

In a further embodiment of the invention the effective electrical contact area is varied in direct proportion to the desired variation in current density.

In a still further embodiment of the invention the effective electrical contact area is varied in a direction in which the current density is to be varied.

In one embodiment of the invention the effective electrical contact area is reduced for reducing the current density, and advantageously is progressively reduced for progressively reducing the current density.

In another embodiment of the invention the effective electrical contact area is varied transversely across the active region. In an alternative embodiment of the invention the effective electrical contact area is varied in a longitudinal direction along the active region. In a further alternative embodiment of the invention the effective electrical contact area is varied in both the transverse and longitudinal direction.

In a still further embodiment of the invention the effective electrical contact area is maintained constant in a direction at right angles to the direction in which the effective electrical contact area is varied.

In a further embodiment of the invention the junction defined by the semi-conductor medium is a p-n junction.

In one embodiment of the invention the first and second electrical contacts are located on respective opposite sides of the semi-conductor device.

In one embodiment of the invention the semi-conductor device is an optical semi-conductor device, the longitudinal direction of the active region being defined by the direction of light propagation.

Preferably, the effective electrical contact area is varied for forming a current density profile in the active region which substantially coincides with the light intensity profile in the active region.

The invention will be more clearly understood from the following description of some embodiments thereof which are given by way of example only with reference to the accompanying drawings, in which:

Fig. 1 is a perspective view of an optical semi-conductor device according to the invention,

Fig. 2 is a graphical representation of current density and light intensity level in the active region of the optical semi-conductor device of Fig. 1,

Fig. 3 is a plan view of a portion of the device of Fig. 1,

Fig. 4 is an enlarged plan view of a part of the portion of

Fig. 3,

Fig. 5 is a plan view of a portion of an optical semi-conductor device according to another embodiment of the invention,

Fig. 6 is a graphical representation of current density in the active region of the optical device of Fig. 5,

Fig. 7 is a plan view of a portion of an optical semi-conductor device according to another embodiment of the invention,

Fig. 8 is a graphical representation of current density in the active region of the optical device of Fig. 7,

Fig. 9 is a plan view of a portion of an optical semi-conductor device according to a further embodiment of the invention, and

Fig. 10 is a graphical representation of current density in the active region of the optical device of Fig. 9.

Referring to the drawings and initially to Figs. 1 to 4 there is illustrated an optical semi-conductor device, in this embodiment of the invention a broad area laser device indicated generally by the reference numeral 1. The laser device 1 comprises a semi-conductor medium 2 formed by a p-type layer 4 and an n-type layer 5 which defines a p-n junction 6. A pair of electrical contacts, namely, a first electrical contact 9 and a second electrical contact 10 are located at opposite surfaces of the medium 2, namely, the first contact 9 is located on the upper surface of the p-type layer 4, while the second contact 10 is located on the lower surface of the n-type layer 5. The first and second contacts 9 and 10 are in electrical contact with the respective layers 4 and 5 for pumping current through the p-n junction 6 for

developing an active region 12 at the p-n junction 6 in which light is generated. The second contact 10 extends over and is in electrical contact with the entire surface of the medium 2, while the first contact 9 defines an outline contact area which is indicated by the area bounded by the broken lines 11, which in turn, defines the active region 12 in the p-n junction 6. The first contact 9 is also shaped for varying the current density transversely across the active region 12 in the direction of the arrows A and B for avoiding regions of unsaturated gain adjacent respective opposite edge regions 15 and 16 of the active region 12. In other words, the current density is varied in the active region 12 in a direction transversely of the direction of light propagation in the active region 12. In this embodiment of the invention, the first contact 9 comprises a main contact 18 which extends longitudinally along the active region 12 in the direction of light generation and a plurality of spaced apart secondary contacts formed by finger contacts 19 which extend transversely from and are electrically connected to the main contact 18. The main contact 18 and the finger contacts 19 are in effective electrical contact with the p-type layer 4, and thus define an effective electrical contact area 17 through which current is pumped through the upper surface of the p-type layer 4. As can be seen the effective electrical contact area 17 is entirely within the outline contact area 11 which is also defined by the first contact 9. The finger contacts 19 taper outwardly from their respective proximal ends 20 to their respective distal ends 21 so that effective electrical contact area 17 decreases in the direction of the arrows A and B, in other words, in the direction in which it is desired that the current density in the active region 12 should decrease. However, to avoid grating effects in the longitudinal direction of light propagation in the active region 11 the spacing between adjacent edges 24 of the finger contacts 19 in the direction of light propagation is such as not to exceed the effective diffusion distance of current in the p-type layer 4 so that current from the adjacent finger contacts 9 combines in the active region 12 due to the diffusion. In this

way, while the current density reduces towards the edges 15 and 16 of the active region 12, the current density remains constant in the longitudinal direction, thus avoiding grating effects.

Referring to Fig. 2 a plot of current density profile across the active region 12 from the edge 15 to the edge 16 is illustrated by the curve 25. The profile of the light intensity of the laser light generated in the active region 12 across the active region 12 from the edge 15 to the edge 16 is also illustrated in Fig. 2. As can be seen the current density profiles substantially follows the light intensity profile across the active region 12, and accordingly, unsaturated gain near the edges 15 and 16 of the active region 12 is virtually entirely avoided.

This is achieved by virtue of the fact that the effective electrical contact area between the first contact 9 and the semi-conductor medium 2 is reduced in the direction in which the current density is to be reduced. The current density through the p-type layer 4, and in turn, through the p-n junction 6 decreases in the direction of the arrows A and B from the proximal ends 20 to the distal ends 21 of the finger contacts 19. However, the current travelling from the finger contacts 19 through the semi-conductor medium 2 on reaching the p-n junction 6 diffuses before reaching the active region 12. The amount of diffusion depends on the lateral diffusion length in the p-type layer 4, the thickness of the p-type layer 4 between the active region 12 and the first contact 9, the doping concentration in the p-type layer 4 and the external bias. Therefore, the local current density in the active region 12 and thus the local gain in the active region 12 is a function of the effective electrical contact area 17 of the first contact 9 with the semi-conductor medium 2, as well as the diffusion parameters. It is desirable that the current density in the active region 12 should remain constant in the longitudinal direction along the direction of light propagation to avoid induced grating in the active region 12, which would scatter light out of the active region 12, and this,

as discussed is achieved by controlling the spacing between adjacent edges 24 of the adjacent finger contacts 19 so that the current pumped from adjacent finger contacts 19 will combine in the active region 12 due to diffusion therein. However, such grating effect in the longitudinal direction of light propagation may be desirable in certain implementations of the semi-conductor device 1, and in which case this would be achieved by also varying the effective electrical contact area 17 of the first contact 9 in the direction of light propagation.

In use a voltage is applied across the contacts 9 and 10, thereby pumping a current through the p-n junction 6 for forming the active region 12. The current density across the active region 12 is as illustrated in Fig. 2.

The advantages of the invention are many. A particularly important advantage of the invention is achieved by virtue of the fact that the current density across the active region is controlled by the shape of the first contact 9. In other words, the current density across the active region 12 is controlled by the area and shape of the effective electrical contact area defined by the first contact . Thus, the current density across the active region can be controlled without the need for doping the semi-conductor medium, or without the need for any other external or internal means for controlling current density. By controlling the current density across the active region unsaturated gain near the edges of the active region is avoided. A particularly important advantage of the invention is that since the current density is controlled by altering the effective electrical contact area defined by the first contact 9, the upper contact 9 can be maintained at the same voltage. In other words, one single electrical connection to the first contact 9 is all that is required, since the main contact 18 and the finger contacts 19 are electrically connected with each other.

Referring now to Figs. 5 and 6 there is illustrated an upper first

contact 30 also for use on a semi-conductor laser device according to another embodiment of the invention. The first contact 30 is substantially similar to the first contact 9 of the laser device 1, and similar components are identified by the same reference numerals. The main difference between the first contact 30 and the first contact 9 is that the main contact area 18 is considerably wider than the main contact area 18 of the first contact 9 of the laser device 1, and additionally, the finger contacts 19 do not taper from their proximal ends 20 to their distal ends 21.

Fig. 6 illustrates the profile of the current density which is developed across the active region of the p-n junction of the semi-conductor medium of this laser device from the opposite edges which would correspond to the opposite edges 15 and 16 of the active region 12 of the laser device 1.

Fig. 7 illustrates an upper first contact 40 of a semi-conductor laser device according to another embodiment of the invention, the first upper contact 40 is substantially similar to the first contact 9 of the laser device 1, and similar components are identified by the same reference numerals.

Fig. 8 illustrates the current density profile developed by the first contact 40 across an active region.

Fig. 9 illustrates an upper first contact 50 for a semi-conductor laser device according to a still further embodiment of the invention. In this embodiment of the invention, the contact 50 comprises a main central contact 51 which is substantially free of through holes 52, and respective opposite side secondary contacts 53 in which a plurality of the through holes 52 are formed. As can be seen the number of holes 52 per unit area progressively increases from the main contact 51 to the respective side edges 54 of the secondary contacts 53. Thus, progressively decreasing the effective electrical contact area of the secondary contacts 53 of

the first contact 50 in the direction in which the current density is to be reduced.

Fig. 10 illustrates the current density profile developed across an active region between opposite edges which correspond to the edges 15 and 16 of the active region 12 of the laser device 1 of the laser semi-conductor device according to this embodiment of the invention.

It is envisaged that instead of providing secondary side contacts 53 extending from the main contact 51, a plurality of discrete secondary contacts may be provided on respective opposite sides of the main contact 51 in which case, the discrete secondary contacts would be electrically connected together and electrically connected to the main contact 51, thereby necessitating the need for only a single connection to the first contact. It is envisaged that the number or area of the discrete secondary contacts per unit area would be progressively decreased from the main contact to the outer ones of the discrete secondary contacts.

While the first contact 9 has been described as being shaped for developing current density profile across the active region of a semi-conductor laser device which increases progressively from the respective opposite side edges to a central peak value, it will be appreciated that the first contact may be shaped to develop any other desired current density profiles.

While the semi-conductor device has been described in all the embodiments of the invention as being a laser device, the semi-conductor device could be any other type of device besides a laser device in which it is desired to develop a varying current density profile in the active region of the junction, be it a p-n junction or otherwise.

While in the embodiments of the invention described the upper contact has been described as being shaped to develop the varying

current density, it will be readily apparent to those skilled in the art that the lower contact could be shaped or profiled to develop the desired current density profile. Indeed, in certain cases, it may be desirable to shape both the upper and lower contacts to form the desired current density profile.

The semi-conductor medium instead of being a two layer medium may be a multi-layer medium.

The invention is not limited to the embodiments hereinbefore described which may be varied in construction and detail.

F.F. GORMAN & CO.

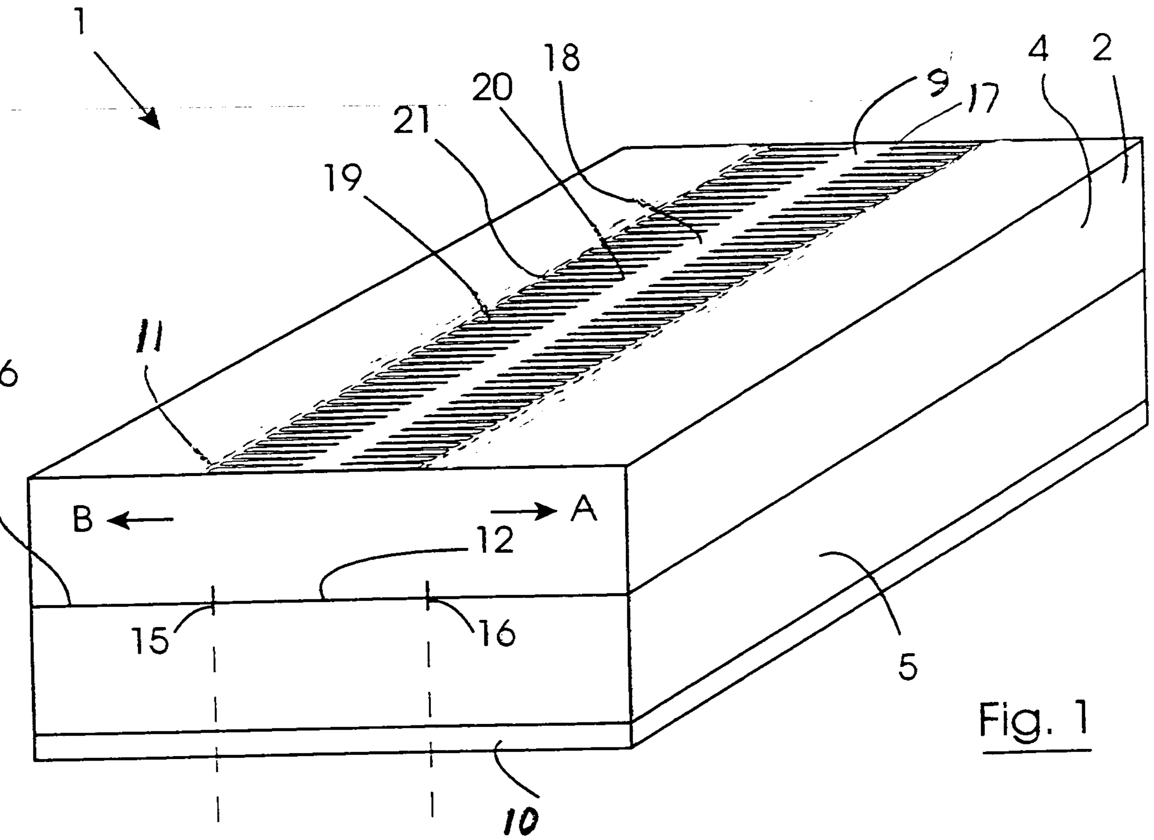

Fig. 1

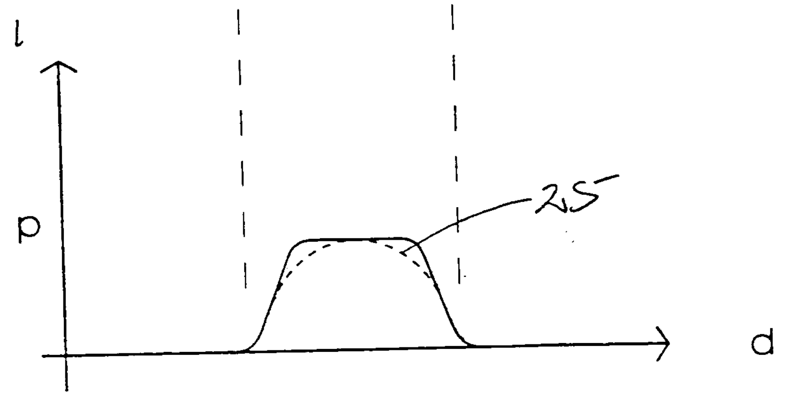

Fig. 2

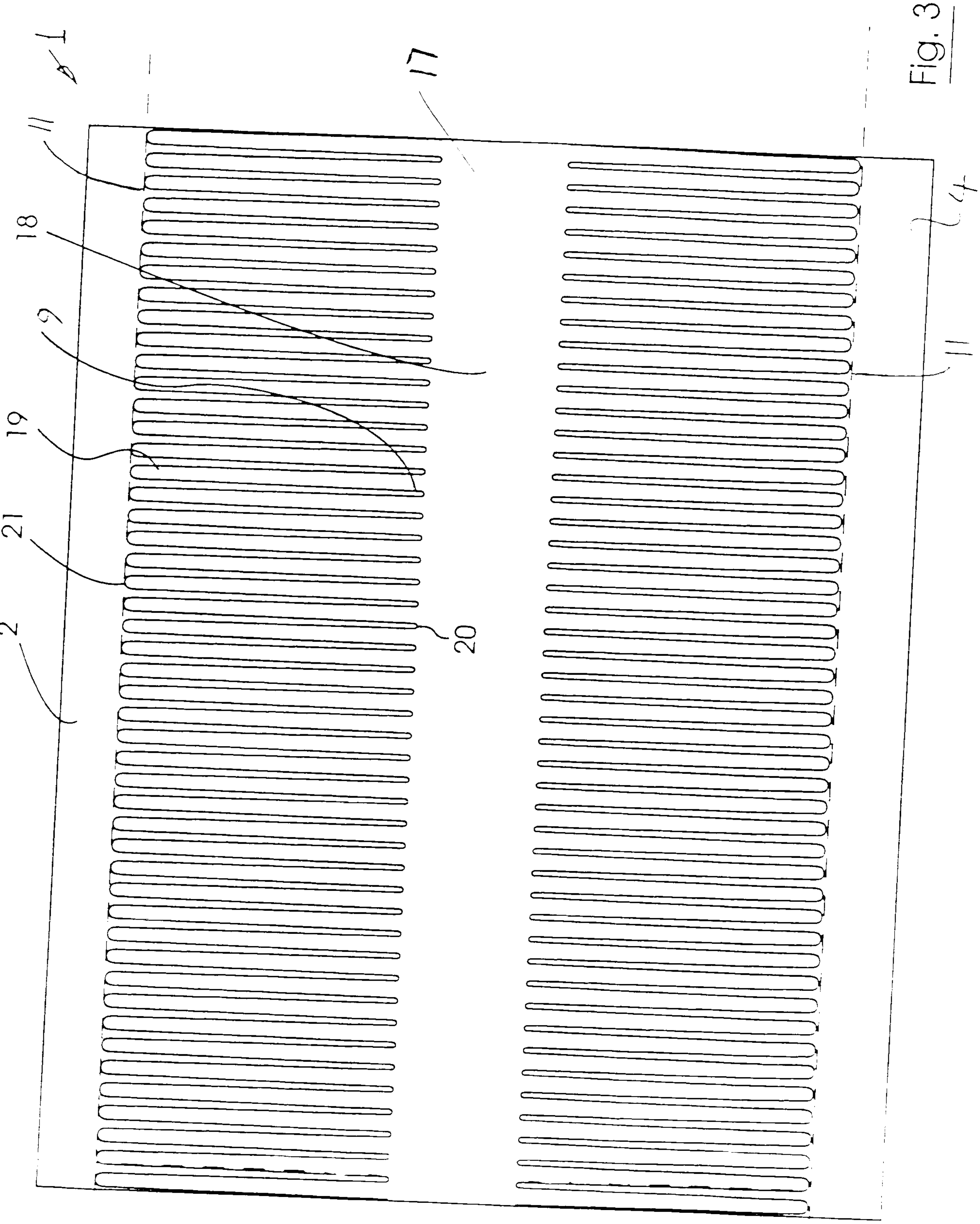

Fig. 3

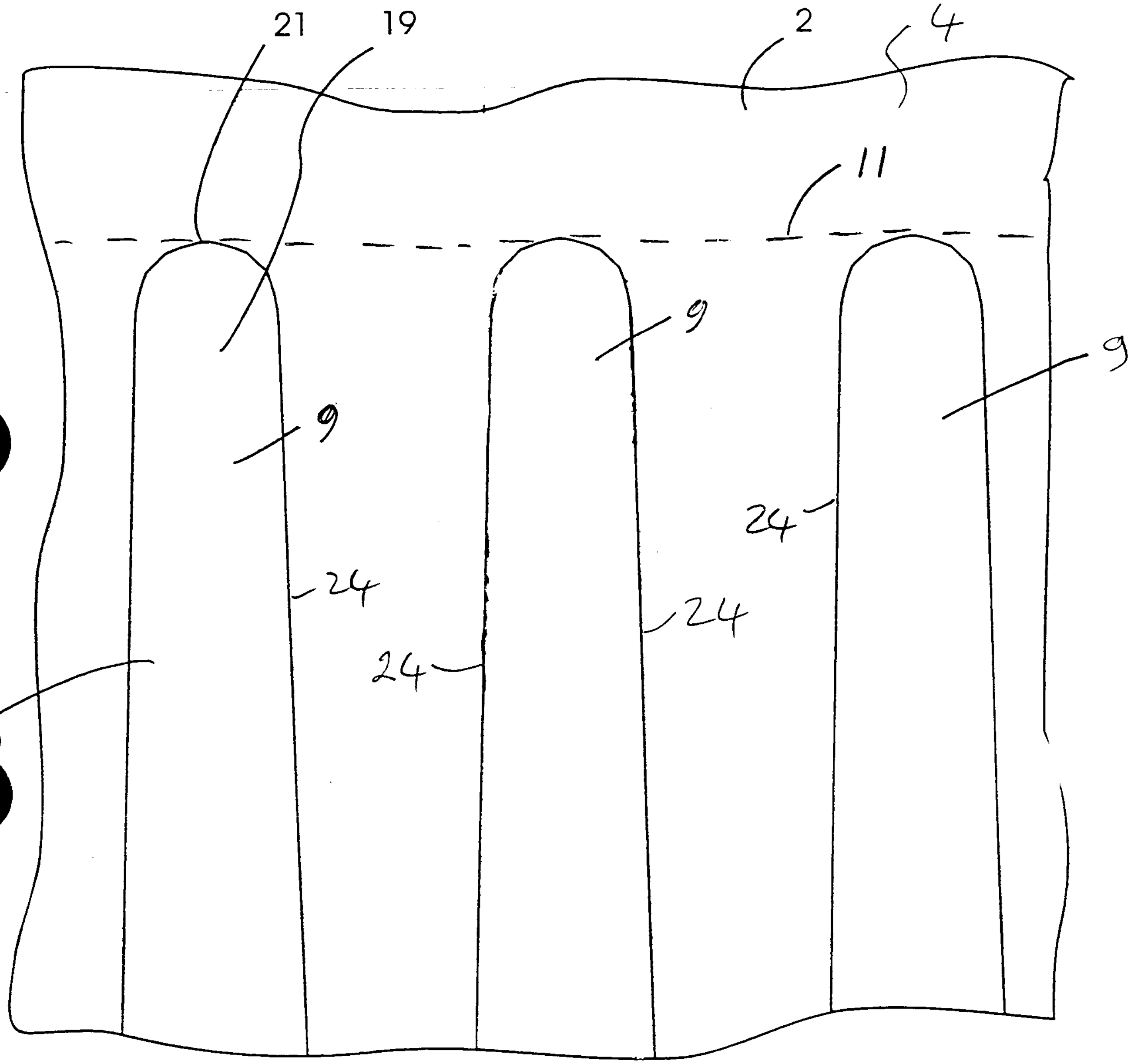

Fig. 4

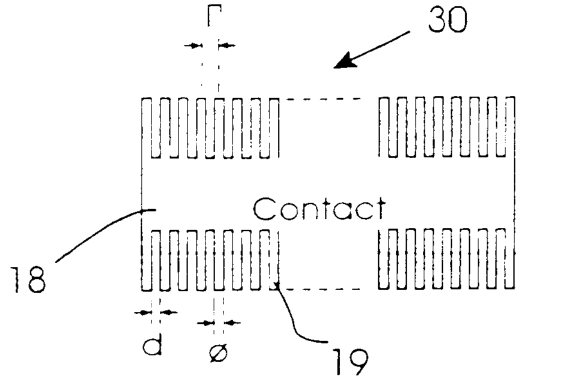

Fig. 5

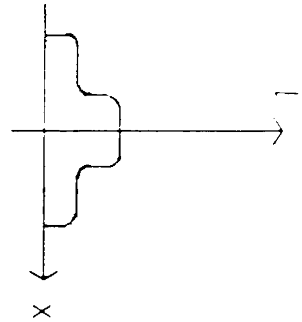

Fig. 6

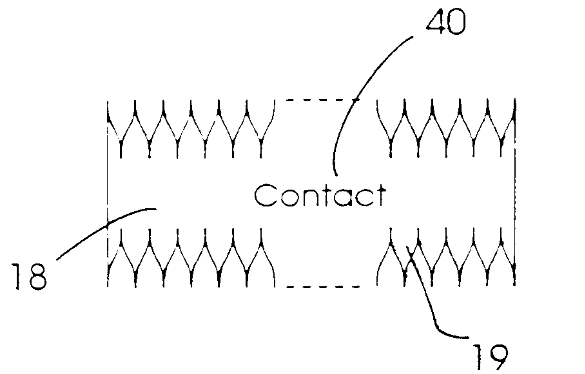

Fig. 7

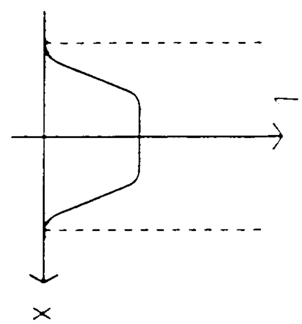

Fig. 8

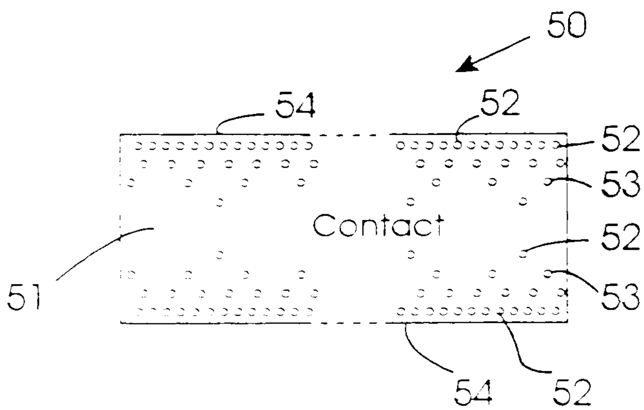

Fig. 9

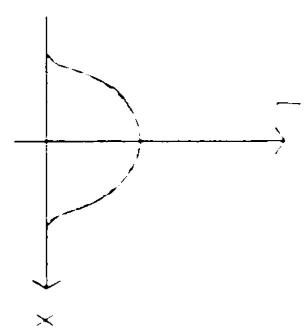

Fig. 10